# POST-OCCUPANCY MONITORING OF TWO FLATS IN MADRID: DEVELOPMENT AND ASSESSMENT OF A MIXED METHODS METHODOLOGY



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Fig.1: Figure 1. Facade of non-renovated and renovated buildings

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?


**Research summary**

Recent research has shown large differences between the expected and the actual energy consumption in buildings. The differences have been attributed partially, to the assumptions made during the design phase of buildings when simulation methods are employed. More accurate occupancy profiles on building operation could help to carry out more precise building performance calculations. This study focuses on the post-occupancy evaluation of two apartments, one renovated and one non renovated, in Madrid within the same building complex.

The aim of this paper is to present an application of the mixed-methods methodology (Creswell, 2007) to assess thermal comfort and occupancy practices used in the case studies, and to discuss the shortcomings and opportunities associated with it. The mixed-methods methodology offers strategies for integrating qualitative and quantitative methods to investigate complex phenomena. This approach is expected to contribute to the growing knowledge of occupants’ behaviour and building performance by explaining the differences observed between energy consumption and thermal comfort in relation to people’s saving and comfort practices and the related experiences, preferences and values.



**Keywords**: Post-occupancy, Energy, Building performance, Monitoring, Occupant behaviour

## 1. Introduction

In Europe the building sector represents 40% of the European Union’s (EU) total energy consumption (2010/31/EU, D.). Therefore, the importance of improving energy efficiency in existing buildings. In order to achieve this objective, the first step should be to have calculation methods that determine the energy performance of buildings.

For this purpose, dynamic thermal simulation programs are used as predictive tools. However, numerous studies (Majcen et al., 2013; Branco et al., 2004 ;Johnson & Wingfield, 2010; Galvin et al., 2013) have shown that the actual energy performance of buildings does not correspond to the calculated performance. Post-occupancy monitoring evaluations have become an important method in order to evaluate the actual energy performance of buildings. There are different types of post-occupancy monitoring methods according to the objective of the evaluation, the depth and nature of the study, the audience of the feedback, and the resources available for the evaluation (Guerra-Santin &Tweed, 2014). This paper focuses on two case studies in the city of Madrid where a post-occupancy monitoring evaluation is performed.

The collaboration between ABIO-UPM Research Group of the Technical University of Madrid (UPM) and the Delft University of Technology (TU Delft) has enabled us to carry out this study. The SusLab Integrated Toolkit and its proposed methodology based on mixed methods have been used in this study. Both of them are outcomes of the SusLabNWE project, an Interreg European research project that aimed at developing a research platform to support the collection of objective and subjective data on thermal comfort and occupancy practices in real homes and for long periods of time. Moreover, data of energy metering for gas and electricity have been collected in order to have more information about occupant´s behaviour.

The aim of this paper is to present an application of mixed-methods methodology to assess thermal comfort and occupancy practices used in the case studies, and to discuss the shortcomings and opportunities associated with it. For this reason, this paper is divided in two main parts. Firstly, the approach, the monitoring procedure and the equipment used are described. Secondly, preliminary results and conclusions are presented, based on the first months of the monitoring campaign.

## 2. Approach

The mixed-methods methodology offers strategies for integrating qualitative and quantitative methods to investigate complex phenomena. In this case study, it has been applied to integrate monitoring of both subjective data on thermal comfort and comfort related practices, and objective data on indoor climate and energy consumption. The building monitoring process consists on four types of data collection: 1) the measurement of building envelop parameters, 2) the energy metering for gas and electricity, 3) the monitoring of the indoor parameters in the dwellings, and 4) the collection of subjective data on comfort and related practices from the occupants.

### *2.1 Building envelop parameters*

Two non-intrusive methods were selected to evaluate the building envelop: U-value measurement and infrared thermographic survey. The U-value was measured with the multifunction TESTO 435-2, instrument with surface temperature probe to determine U-value, and radio probe for temperature and humidity. This instrument measured the heat loss in a building element, in this case the

façade. The protocol followed was performed for 24 hours in each flat and the data was collected every 10 min. The aim was to compare the theoretical U-value with the information collected on the facade, and the measured value, in order to calibrate the simulation model.
The Infrared images were taken with a camera FLIR-E series with a pixel resolution of 4,800 (80x60). Interior and exterior images were taken. The infrared exterior survey was performed of the building´s north façade in the morning. The infrared interior survey was performed mostly during early hours in the morning. In both cases, times when the facade was getting direct solar radiation were avoided, in order to prevent alteration of the information. Through the observation of images obtained, the temperature in different parts of the facade was evaluated with the infrared camera, and heat gains and losses were located.

*2.2 Energy metering for gas and electricity*
Electricity metering was performed by using an energy monitor that shows real time information; a wireless signal is sent every six seconds from a transmitter attached via a CT Jaw to the meter and then to the display. The energy consumption can be viewed easily, showing changes in power consumption when different electrical appliances are used. On the other hand, a surface temperature probe of the boiler inlet has been used as proxy indicator for gas consumption. This information allows to analyse occupant´s behaviour and the use of the boiler.

*2.3 Monitoring of indoor parameters*
The SusLab Toolkit provides a local network based on zigbee technology to collect sensor-based data automatically as well as personal data by means of self-reports. Sensor boxes were deployed to collect indoor climate data (temperature, humidity and $CO_2$ level) as well as relevant contextual data such as sound, light and movement (Figure 2). The sensor boxes were located in each room of the flat, excluding the bathroom and kitchen for safety reasons. Five sensor boxes were installed in each flat. The parameters were measured and sent to a central database on 16 seconds intervals. The data can be downloaded at any interval desired by the researcher. For this preliminary analysis, a 10 minutes interval was chosen.

2.4 *Collection of subjective data on comfort and related practices from the occupants*
The comfort dial, is a physical device connected to the same local network that allows occupants to report their current perception of comfort on a seven-level scale from cold to very warm (Figure 3). The objective and subjective data collected with the sensor box and the comfort dial were integrated to the data on energy consumption (gas and electricity) in order to understand the occupancy patterns of the users of the flats. The integration of the data was done visually per house. Graphs were created to show the indoor conditions of the flats in relation to the outdoor temperature, and energy consumption for heating and cooling. After this analysis, the residents of the flats were interviewed to confirm or give further information on the assumptions made based on the analysis of the data. During the interviews, the residents were asked for a walkthrough of their homes providing with descriptions and re-enactments on the way they usually control their indoor environment and on their daily practices related to energy consumption. The topics investigated were the use of windows to ventilate their homes, the use of the heating or cooling systems, cooking

habits, appliances and electronics use, and presence at home.

*2.5 Participants*

The occupants of both renovated and non-renovated apartments were female older adults living alone. The non-renovated occupant spends most of the week days at home while visiting family every weekend. The renovated occupant performs part-time voluntary work during the week and visits family sporadically.

*2.6 Procedure*

The measurements were designed in cycles of four months in a year period to match the four weather seasons. In each cycle data was collected, analysed and used to interview participants. This paper presents the results of the winter cycle.


Fig 2: Suslab Sensor Box (above) and Comfort Dial (below)

**3. Results**

Preliminary results have shown the advantages of the mixed method methodology to obtain detailed and understandable data on the occupancy patterns followed by the residents of the dwellings. The data was integrated and analysed with the objective of obtaining information on occupancy patterns that could be used on building simulation programs. Data integration was on the presence of people at home, ventilation patterns and used of the heating and cooling system.

*3.1 Building thermal quality*

Figures 4 and 5 show the exterior wall U-value in dwelling 1 and 2 respectively. The results show the thermal performance of the envelope of the dwelling 1 (renovated) is better than the dwelling 2 (non renovated). The theoretical U-values were 0.66 (dwelling 1) and 2.07 (dwelling 2). Generally, the monitored U-values are more similar to the theoretical ones in renovated buildings rather than those in existing buildings. This is due to the insulation that helps to stabilize the facade thermal flux, especially in this type of facade consisting of only one solid brick feet, where the mortar among the bricks has deteriorated over time.

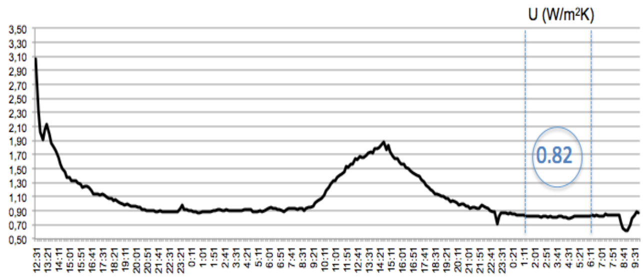


Figure 4. Exterior wall U-value, Dwelling 1

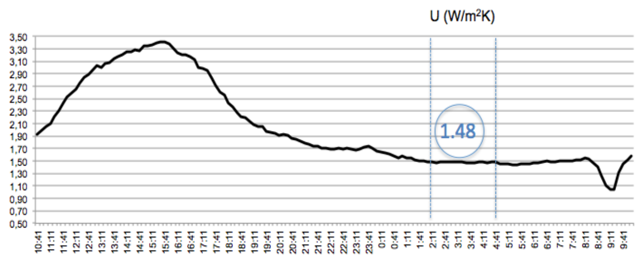


Figure 5. Exterior wall U-value, Dwelling 2

Fig.6 shows outdoor images of the building that has not been renovated. It is possible to see the mortar among the bricks indicating the lack of insulation. At the same time, the predominant yellow colour under the window indicates that the heating system is turned on inside the house, and the heat flow is being lost through the facade. Fig.7 shows heat losses due to air infiltration around the window, a common problem in this type of non-insulated buildings.

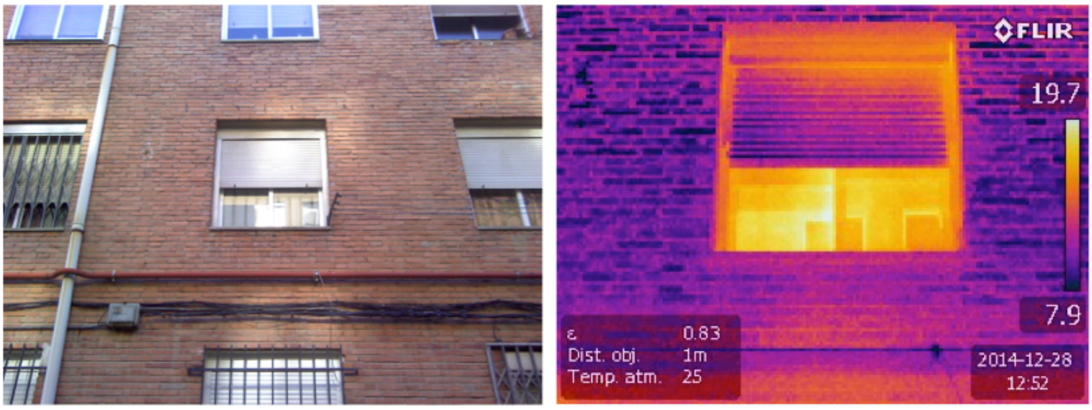


Fig 6: Outdoor infrared image. Non-renovated building.

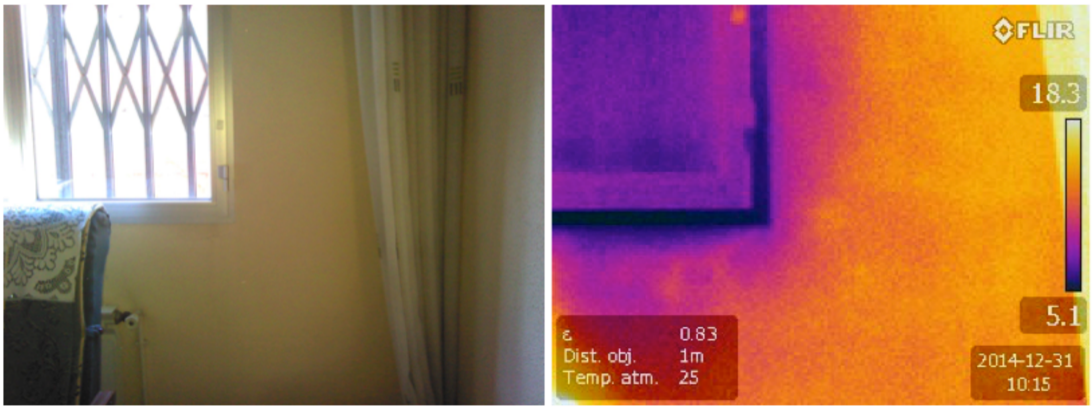


Fig 7: Indoor infrared image. Non-renovated building

3.2 *Building occupancy*

To determine the presence of people at home, the electricity consumption appliances and electronics at home was investigated. Figure 8 and 9 show the likelihood that the residents will be home per hour for every day of the week based on the electricity consumption of electronics. The patterns showed in the figures were confirmed by the residents of the flats during the interviewing sessions.

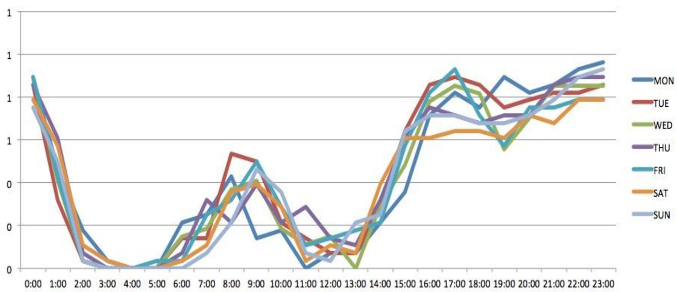


Figure 8. Presence at home per day of the week based on electricity consumption, Dwelling 1

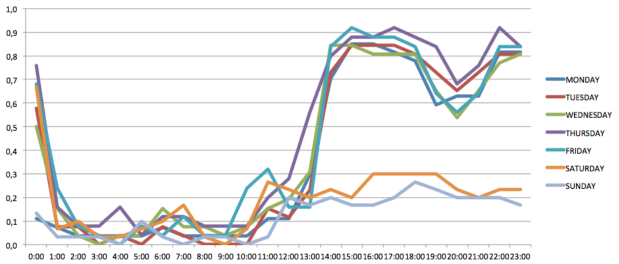


Figure 9. Presence at home per day of the week based on electricity consumption, Dwelling 2

To determine the use of the heating system, we used the surface temperature of the boiler inlet to define the hours in which the system was on. Dwelling 1 (renovated) has been provided with a manual thermostat for temperature control, while Dwelling 2 (not renovated) only has an on/off function for controlling the boiler. In Figure 10, the proxy for boiler use (surface temperature of the boiler inlet) shows that in the renovated house, the heating patterns does not follow a determined time schedule. This was confirmed by the resident during the interview. The resident informed to only turn on the heating when she thinks it is necessary. During the first days of the winter, the heating was on for only a few days. The low use of the heating is caused by the higher thermal performance of the building, and because the resident reported to almost never feel cold at home, as she is mostly physically active. Figure 11 shows the proxy indicator for gas consumption for Dwelling 2. The figure shows clearly the time of the day in which the boiler is (manually) turned on. This pattern was also confirmed by the resident of the flat.

In order to determine the temperature setting preferred by the user, the indoor temperature was investigated. Figures 10 and 11 show the indoor temperature per room in each of the dwellings. Dwelling 1 shows that the heating is turned on at different times of the day and for different periods of time. The figure also shows the feedback from the user regarding thermal comfort. From this, we can ascertain that the preferred temperature lies between 22 and 24°C. The measurements in Dwelling 2 indicate that the temperature sought by the user is around 23°C. The user does not know the temperature of the flat, and so, the control of the boiler is based on a time schedule. The boiler is manually turned on around midday after ventilating the dwelling, and turned off around the midnight. However, indoor temperature decreases in the early evening because of the efficiency mode of the boiler.

The drops in the temperature clearly show the instances in which the windows were open for ventilation (blue dotted arrows). The resident confirmed to open all windows in the house for less than one hour during the winter, and to turn on the heating after ventilating the flat.

## 4. Conclusions

The mixed-method methodology allows us to obtain qualitative results about the occupancy patterns. Objective data on indoor conditions and energy consumption were integrated to subjective data on thermal comfort ratings to determine the comfort of the users. To determine their comfort needs and ability to reach comfort at home, interviews were focused on heating and ventilating practices, and on actions taken to reach thermal comfort. The measurements and interviews also focused on determined concrete occupancy patterns for building simulation.

The study showed many opportunities related to the capacity to obtain accurate and reliable information on occupants' behaviour, however, there were instances in which more information was needed to validate assumptions made based only on the measured data.

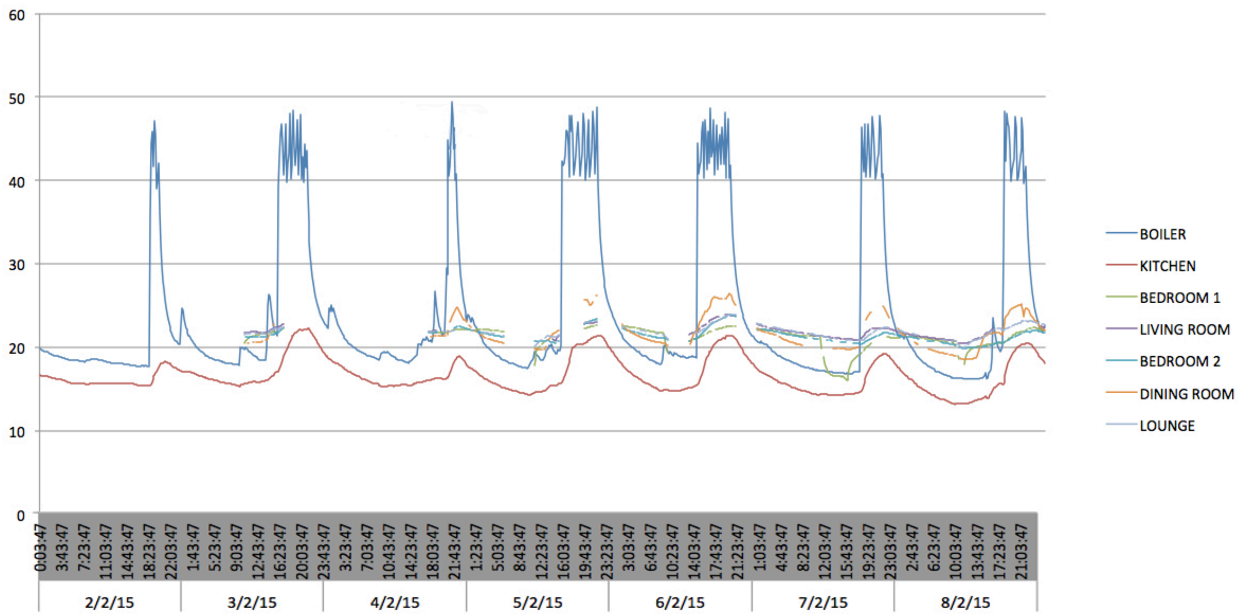


Figure 10. Indoor temperature, surface temperature of boiler inlet in Dwelling 1

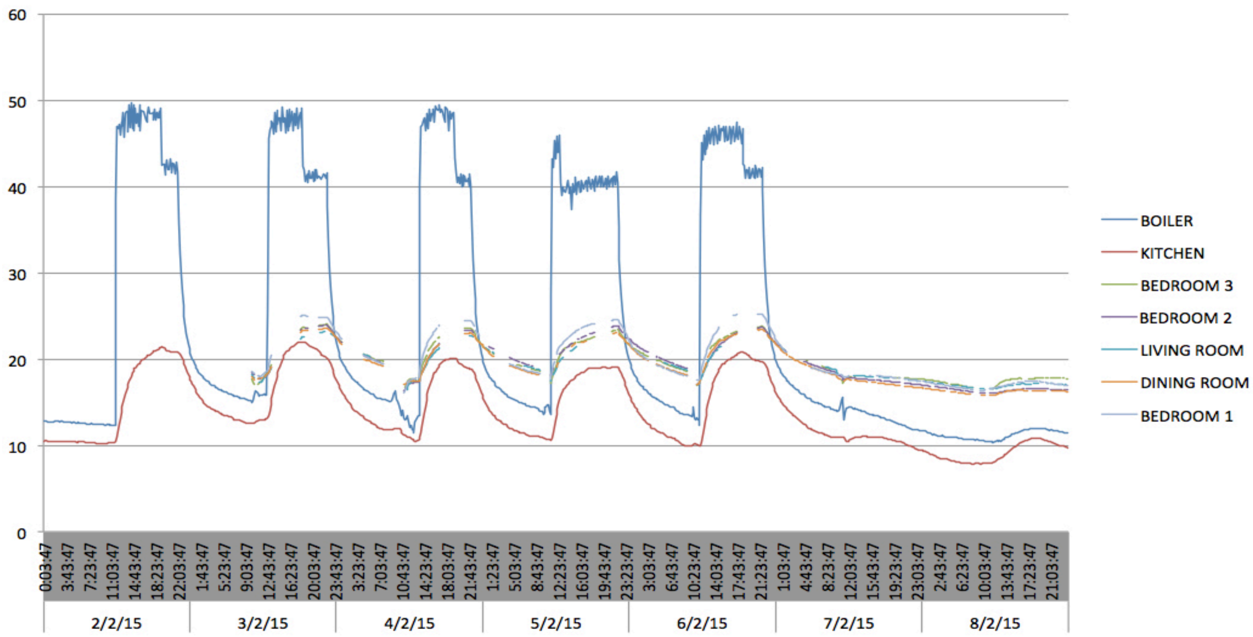


Figure 11. Indoor temperature and surface temperature of boiler inlet in Dwelling 2

One of the most important questions was whether the indoor temperatures measured inthe dwellings were those desired by the users, since this is related to both the control of the heating system, and the thermal properties of the building. The data allowed making sound assumptions, but only with the feedback from the users (comfort dial in dwelling 1 and interview in dwelling 2) we were able to corroborate the information.

We found some limitations related to this type of study, the main limitation is regarding the use of monitored data for building simulation.
The results of the analysis will be always associated to a specific case study (i.e. climate, occupant profile, lifestyle). The second main limitation is based on the practicality of this type of study; the success of monitoring campaigns will always depend on the accessibility to the building and the cooperation of the occupants. The third limitation is regarding the measuring devices and other instruments for data collection. Many of the available equipment are still expensive and their installation can potentially be problematic (to either occupants or researchers). Issues related to wires, lack of Internet connection, lack of power plugs, interference etc., are among the many issues that can be encountered. On the other hand, the occupants should be able and willing to provide their time for answering questionnaires or being interviewed. The simplification of data collection methods and the determination of the most informative parameters to measure, before the deployment of equipment and selection of users, are necessary for a successful campaign.

## 5. Acknowledgments

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